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Amalgamation and refining of high grade silver ores containing arsenic and antimony

Edwin Bryant Thornhill

Robert Emmett Dye

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AMALGAMATION AND REFINING OF HIGH GRADE SILVER ORES
CONTAINING ARSENIC AND ANTIMONY. ⁵⁹⁹

By

E. BRYANT THORNHILL
and
ROBERT E. DYE

A

THESIS

submitted to the faculty of the
SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI
in partial fulfillment of the work required for the
Degree of
ENGINEER OF MINES
Cobalt, Ont., Canada
1914.

Approved by.....

Assistant Professor of Metallurgy and Ore Dressing.

19580

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**AMALGAMATION AND REFINING OF HIGH GRADE SILVER ORES
CONTAINING ARSENIC AND ANTIMONY.**

General Discussion.

The advantage of shipping refined silver bullion over the shipment of concentrate to a smelter has been apparent to mine operators in this district for years but not till recently was the project undertaken by the Buffalo Mines Limited, Cobalt, Ont., Canada. Early in 1912 experiments were conducted by H. G. S. Anderson with this end in view. The results of these experiments led to the erection of an amalgamation plant, the design and construction of which was carried out by Mr. Anderson.⁽¹⁾

The plant was completed and operation begun in Nov. 1912 at which time E. Bryant Thornhill took charge. The plant has been in successful operation since that time.

The advantages of shipping refined bullion over the shipment of a concentrate to the smelter may be summed up somewhat as follows;- When the

(1) See thesis submitted to Mo. School of Mines and Metallurgy in 1912 for the degree of Engineer of mines.

Page 2.

treatment cost is the same in both cases the mine benefits by the promptness of settlement and the difference between freight on ore and express on bullion. An additional consideration which is no small item is the fact that the mine retains the residue from ore treatment and in selling it receives pay for the arsenic, cobalt and nickel as well as for the small amount of silver remaining. In this way the mine realizes on a much greater proportion of the silver as well as on the various by-products, for which the smelter gives no credit when buying the raw ore.

It is not the hope in this paper to set forth facts that are entirely new as similar subjects have been treated in the technical magazines. It is rather the aim to set forth some of the specific difficulties encountered here and the ways in which they are overcome. In order to do this clearly it is necessary to make the discussion of the plant more or less complete even tho this may entail the enumeration of some facts which have received previous discussion elsewhere.

Page 3.

Products Treated.

The products treated at the High Grade Plant are;-

I. Jig concentrate from the jigs at the Low Grade Mill. This product is dried and reduced in a ball mill to pass 20 mesh. The metallics on 20 mesh are sent to the tilting furnace at the High Grade Plant and the pulp is sent for treatment in the tube mill.

No.1 ore which is hand picked under ground is very similar to the jig concentrate and is treated with it.

Following is a complete analysis of this class of ore. The determinations were made by Ledoux and Company, New York.

Silica (fusion) - - - - -	-19.46%
Alumina - - - - -	4.56%
Iron (metallic) - - - - -	8.70%
Lime - - - - -	-4.90%
Magnesia - - - - -	2.67%
Manganese - - - - -	0.03%
Lead - - - - -	0.70%
Copper - - - - -	0.28%
Antimony - - - - -	0.64%
Titanium oxide - - - - -	0.20%
Sulphur - - - - -	4.52%

Page 4.

Carbon dioxide -----	6.5 %
Arsenic -----	33.45%
Nickel -----	2.95%
Cobalt -----	7.16%
Silver -----	2000.00 Oz./T.

II. Table concentrate, which is the product from the sand and slime tables, is dried and sent direct to the High Grade Plant for treatment in the tube mill.

An analysis of this class of ore is similar to that of the jigs except that the insoluble and sulphur contents are greater. The proportions of the other elements vary considerable. It is also true that more of the silver contained is held by the complex minerals present than is the case with jigs. The larger part of this is combined in such minerals as proustite, dyscrasite, tetrahedrite, pyrargyrite and argentite.

This class of ore will as a rule carry;-

Arsenic -----	18.00% to 20.00%
Cobalt -----	5.00% to 6.00%
Nickel -----	1.00% to 2.00%
Copper -----	1.00% to 2.00%
Sulphur -----	5.00% to 9.00%
Silver ---	700.0 Oz./t. to 1200.0 Oz./T.

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III. The refinery at the High Grade Plant receives for treatment in the tilting furnace the following,

(a) Precipitate and short zinc from the Low Grade Cyanide Plant. Assay of precipitate is 82.0% silver, of the short zinc 48.0% silver.

(b) Metallics from the mine, picking belt and the ball mill. These metallics carry approximately 90.0% silver with varying amounts of mercury, arsenic, antimony, copper, etc.

Previous Treatment of Products at the Low Grade Mill, Synopsis.

The preliminary crushing of the ore from the mine is accomplished by a gyratory crusher followed by a Blake. This product is further reduced by passing through rolls. Here all the ore is passed over jigs to recover the coarse particles of mineral. This concentrate, which is the product from both the beds and the hutchies, is put through a ball mill and sent to the High Grade Plant for treatment.

The tail from the jigs is passed through rolls followed by a Chilian mill for further reduction. The product from the Chilian mill is classified and

Page 5-a. (Following page 5.)

Note;-

Since the body of the thesis was written a few changes have been made in the plant. The principal change was the substitution of a filter of the Moore type for the Burt filter which was formerly in use. The flow sheet attached is the one of later date.

2382
 2383 second offspring
 2384 *Parus cyathinus* sp.
 2385 pregnant
 2386 larvae with abortion
 2387 *Parus*

Page 6.

concentrated on sand and slime tables. This product is sent to the High Grade Plant for treatment.

The Low Grade Cyanide Mill treats with cyanide all the slimes formed in the grinding of the ore for concentration. The silver precipitate resulting is sent to the refinery at the High Grade Plant for reduction.

Before sending to the High Grade Plant the ore is sampled with an automatic sampler and weighed on Fairbanks Type-Registering Beam scales. The ore is transported by means of an incline tramway fitted with a car. The jigs and the No. 1 ore are put into one bin and the table concentrate into another so that the ores may be treated separately in the tube mill.

The precipitate and short zinc are carefully weighed and sampled, the weights and assays being checked against the returns from the tilting furnace.

The metallies are weighed but no sample can be taken till after melting down, when returns are made for the silver contained in them.

Discussion of the Flow Sheet of High Grade Plant

From the ore bins the ore is drawn by chute to a steel charging hopper which rests in a cradle on a set of Fairbanks scales. The ore is weighed and each car sampled

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to make a composite of the tube mill charge.

The charge consists of 10,000# of ore with 10,000# or more of mercury (never less than 1# of mercury to each ounce of silver in the charge), and 2.5 tons of water made up to a 5.0% KCN solution. The charge is admitted through three 10"x10" charging doors fitted with cross bars and screw clamps for securing in place.

-----Note;- Sufficient water is added here to keep up the volume of the mill solution instead of adding it as a wash thru the out going filter cake as is usually considered best practice in cyanide plants. The addition of water thru the tube mill is found advantageous because of the better results obtained there with a fresh solution than with the stock mill solution which is more or less fouled.

It will be noted also that no lime or other alkali is added to the charge. This is found unnecessary as the nature of the ore and its action with cyanide is such that upon treatment it yields alkali instead of acid as will be noted from titrations on charge sheets. (See under tube mill discussion). - - -

After ten hours grinding, which is sufficient to complete the action, the mill is stopped

Page 8.

and the three charging doors removed and $\frac{1}{4}$ " mesh woven wire screen backed by perforated plate is substituted. The mill is then revolved slowly, the entire charge, except the pebbles, passing through the screen and into the hopper below from where it is conducted to the settler.

The mercury and amalgam is at once drawn from the settler through a mercury trap into the clean-up and thence through a hose to the amalgam bags. Here the mercury is drained free of hard amalgam and conducted to the mercury elevator which delivers it to the mercury reservoir for further use in the tube mill. As soon as all the mercury is drawn from the settler about 3000# of mercury is added to the tube mill with one ton of barren solution. The mill is then revolved discharging this and washing out any amalgam remaining behind in the mill. The mercury is run to the amalgam bags as before. This is followed by 3000# of mercury which is run directly to the settler. After all the mercury and amalgam possible has been drawn off, the charge is allowed to remain in the settler for four to six hours after which the pulp is decanted. This is accomplished by means of a device which consists of a 3" pipe passing through the bottom of the settler and extending

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above the surface of the pulp when the settler is full. This pipe is fitted with a hinge joint at the bottom so the pipe may be swung below the surface of the pulp, allowing the pulp to flow out. This permits of the emptying of the settler from the top which facilitates the separation of the floured mercury from the pulp drawn off. After the settler is partially emptied, barren solution is added which reduces the thickness of the pulp and further aids in the settling of the floured mercury.

The pulp as it is drawn from the settler is conducted to a small mechanical agitator which discharges continuously through an orifice near the top. The pulp is conducted from this point, by a riffled launder, to the boot of the pulp elevator. The material collected in the riffles and in the mechanical agitator is returned to the settler or the tube mill at intervals.

The pulp elevator, by means of launders, delivers the pulp to one of three 10'x10' Dorr agitation tanks where barren solution is added to make a three to one pulp. The cyanide is kept at 25.0#/ton and the agitation continued for 48 to 60 hours. The pulp is then drawn by gravity to a 12'x20' Dorr agitation tank which serves as a collector. From the collector the pulp is drawn off intermittently to a Burt revolving filter which treats

Page 10.

about four tons of dry slime per charge. The pulp discharged from the filter is conducted to a concrete tailing bin by means of a drag conveyor. The residues are then barreled and sold for the arsenic, nickel and cobalt as well as for the silver content.

The effluent solution from the filter, together with the barren solution which is used as a wash, is pumped to a storage tank for pregnant solution. From this tank the solution is conducted to the precipitation tank which is an 8'x10' wood tank fitted with a mechanical agitator. The solution is precipitated in batch lots, this being most convenient owing to the small volume of solution to be handled daily. Precipitation is effected by the addition of caustic soda and aluminum dust. After complete precipitation the solution carrying the precipitate is pumped through a Perrin precipitate press by means of an Aldrich triplex pump. The precipitate is taken from the press at intervals and sent to the refinery while the barren solution flows to a concrete storage sump from which it is drawn as needed for re-use in the plant.

Discussion of the Flow Sheet of the Refinery.

The refinery receives for treatment the following;

I. From the Low Grade Mill,

1. Silver precipitate from zinc shavings.

Page 11.

2., Short zinc containing silver.

3. Mine, picking belt and ball mill
metallies.

II. From High Grade Plant,

1. Amalgam.

2. Silver precipitate from aluminum dust.

Besides these products there is charged
to the various furnaces at different times, material
which is made up of by-products formed in the carrying
out of the process in the refinery. Amongst these are;

I. To the retort furnaces the following,

1. Flue dust from the dust chamber and
cooling pipes.

II. To the tilting furnace the following,

1. Retorted precipitates from the High
Grade Plant.

2. Retorted flue dust.

3. Table concentrate from the grinding
of the slags from refinery.

4. Floor sweepings from the refinery.

5. Second skimmings from the refining
furnace.

6. Remelt slags from the tilting furnace.

Page 12.

III. To the refining furnace is finally charged the following,

1. The sponge resulting from the amalgam.
2. All base bullion coming from the tilting furnace.
3. Metallics from the grinding of slags.
4. The scrap from the previous refining furnace pours.

The Retort Furnaces.

The drained amalgam, which carries from 75% to 85% of its weight in mercury, coming from the amalgam bags, is placed in the retorts in charges of 1200# to 1500# in each furnace, there being four of these furnaces. The retorts are heated by oil flame. The temperature is gradually raised to 800 degrees C in eight hours and maintained at this point for one hour when the fire is turned out and the furnace allowed to cool. The mercury is condensed in a water jacketed cooling pipe and is collected at the back of each retort in a cast iron measuring box. This allows the checking of the mercury and sponge produced against the amalgam charged. After measuring, the mercury is conducted by means of a pipe under the floor, to the boot of the mercury elevator and

Page 13.

from there to the mercury reservoir for further use in the tube mill. After the furnace has cooled the sponge is removed and placed in the vault where it is kept till it is charged to the refining furnace.

The time required for cooling is such that one heat can be run in each furnace in 24 hours. The sponge produced contains from 1% to 3% of mercury and about 90% of silver. The remaining portion is made up largely of the ore which is carried mechanically with the amalgam to the bags.

The silver precipitate from aluminum dust precipitation of cyanide solutions at the High Grade Plant is also treated in the retorts. The operation and the time required is much the same as for the amalgam. The precipitate yields from 30% to 40% of its dry weight in metallic mercury. After retorting, the precipitate carries from 2% to 4% of mercury.

The cost of running a charge in a retort furnace is as follows;

Labor and attention -----	\$1.12
Oil and air -----	2.33
Power for draft -----	.19
Cost of retort per heat ----	<u>3.32</u>
Total cost per heat	\$6.96

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This amounts to a cost of \$0.23¢ per fine Oz. of silver

Each furnace is equipped with a thermo-couple which connects to a milli-voltmeter, graduated to read degrees C and placed on a switch board near the furnaces. By throwing in a switch the operator can tell at any time what the temperature of any of the furnaces is. In addition each couple is attached to a Wm. H. Bristol Pyrometer Recorder which is placed in the office. This keeps a permanent record of the heat which may be referred to at any time.

On pages 15 and 16 will be found records of charges of amalgam and precipitates to the retorts.

On page 17 will be found a temperature chart for one heat.

Tilting furnace.

The tilting furnace receives for treatment the products as enumerated previously. These products are made up into separate charges with varying proportions of fluxes. The fluxes used consist of glass, slag, soda, sand and borax.

The base bullion resulting is placed in the vault till final treatment in the refining furnace. The slag formed is sent to the ball mill for grinding and concentration to recover any silver shot which may be contained in it. The speiss formed (when any is formed)

Amalgamation Plant—Retorting Furnace Report

Heat No. 84.

Date May 9, 1914.

O. & T. 53510

	Amalgam Charged Lbs. Av.	Time Begun	Time Ended	Time of Heat	Retorted Silver Troy Ozs.	Remarks
Retort No. 1	1326.0 lbs.	2:45 P. M.	9:45 A. M.	7.0 hrs.	193.0 Lbs. 193.0 //	
Retort No. 2	1093.0 "	Do.	Do.	Do. "	158.0 Do. "	
Retort No. 3	"			"	"	
Retort No. 4	"			"	"	
Totals	2419.0 lbs.				5119.0 ozs.	

Fineness of Sponge 908.0 Total Fine Ozs. 4648.0

Make all calculations on this sheet

Ratio of Silver to Mercury 0.17

(Attach pyrometer record sheet to this report)

Amalgamation Plant Foreman

Amalgamation Plant—Retorting Furnace Report

Heat No. 44-P

Date May 7, 1914.

O. & T.-55610

	Ppts. Chged. Amalgam Charged= Lbs. Av.	Time Begun	Time Ended	Time of Heat	Retorted Silver Troy Ozs.	Remarks
Retort No. 1	(Wet weight) lbs.			hrs.	ozs.	
Retort No. 2	"			"	"	
Retort No. 3	575.0 "	11:30 A.M.	8:30 P.M.	9.0 "	236.0 Lbs.	"
Retort No. 4	309.0 "	Do.	Do.	Do. "	"	"
Totals	684.0 lbs.				236.0 Lbs. & ozs.	

Fineness of Sponge..... 805.0

Total Fine Ozs..... 2770.0

Make all calculations on this sheet

Ratio of Silver to Mercury.....

Moisture in original charge was 31.7%.

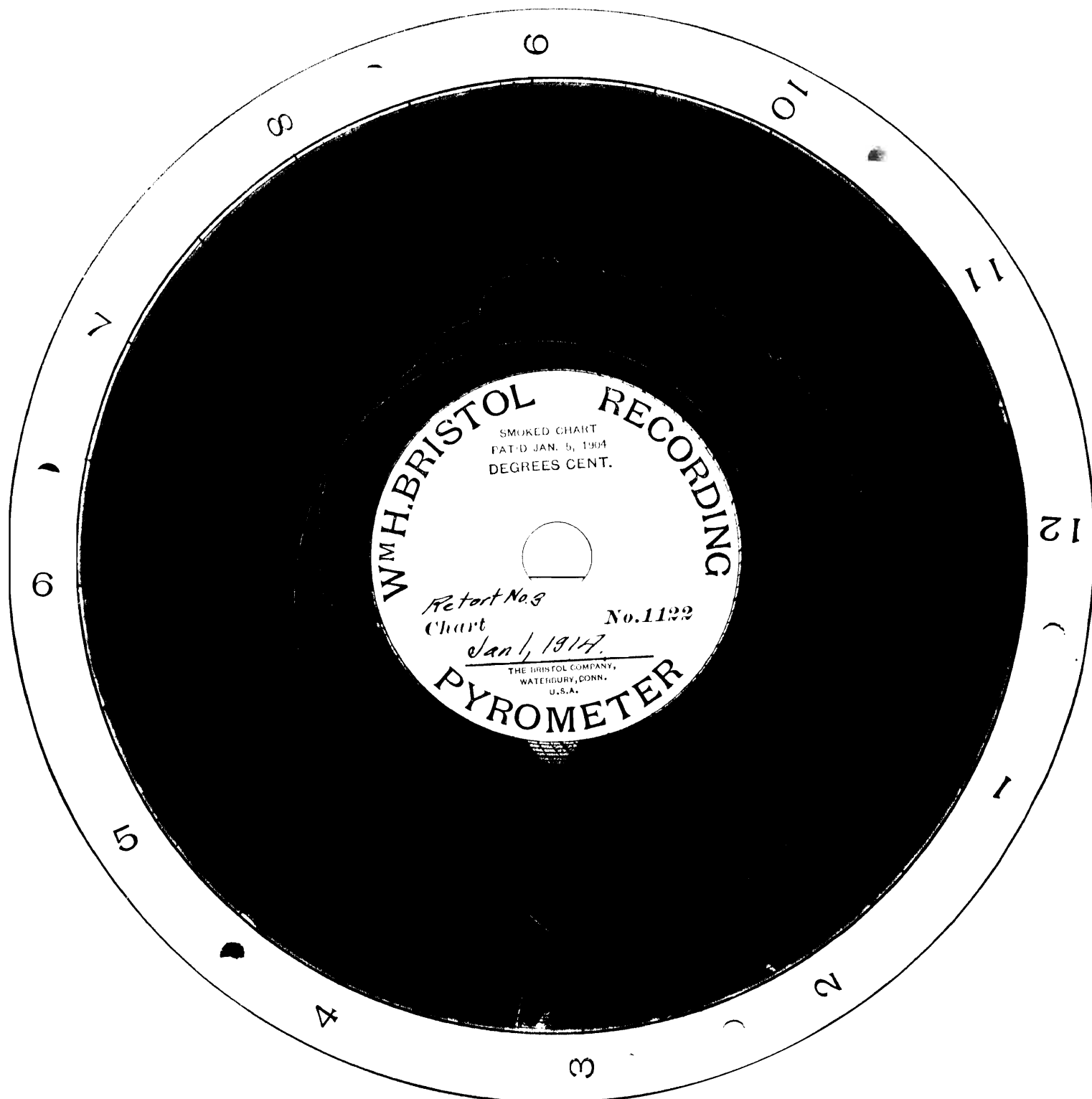
Total mercury recovered was 231.0 Lbs.

Mercury recovered based on dry weight of charge was 49.5%.

(Attach pyrometer record sheet to this report)

.....
Amalgamation Plant Foreman

The record of temperatures on retort No. 3 for Jan. 1, 1914. is self explanatory. One of these is kept for each heat run in each retort furnace. It will be noted that the heating curve lasts for about ten hours and is slightly more irregular than the cooling curve which is about the same length.



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is high in arsenic and carries some cobalt and nickel as well as small amounts of other metals. This is sold as a by-product after desilverization with zinc.

A 20"x20" graphite-clay crucible is used in the tilting furnace. The time required to complete a heat depends upon the size of the charge, the nature of the product treated, the quality of the slag obtained and the heat attainable. The time varies from seven to twenty hours. The aim is to get a fluid slag which is fairly high in silica and which melts readily.

A charge sheet for the tilting furnace will be found on page 19.

The average cost of melting in the tilting furnace, per Oz. of bullion, is as follows;-

Flux -----	0.0266¢
Labor and attention	0.0333¢
Power for draft ---	0.0001¢
Oil and air -----	0.1200¢
Crucible cost -----	<u>0.1000¢</u>
Total per Oz.	0.2800¢

Amalgamation Plant—Tilting Furnace Record

Page 19.

Heat No. 61

Date May 9, 1914

G. & T.-55610

H. G. {	Precipitates	480.0	Lbs. Avoir.	Time charged	2:00 A. M.	a.m.
Charged {	Metallics		" "	Time poured	9:30 A. M.	a.m.
	Slag		" "	Time of heat	7.5	hours
Total Charge		480.0	Lbs. Avoir.			

397.0#	4	Bars Bullion	5789.5	Troy ozs.	890.0	Fine equal to	5152.0	Fine ozs.
Produced {		Scrap		" "		" "		" "
		Slag	208.0	Lbs. Avoir. (for re-melting Ball mill.)				
Total			5789.5	Troy ozs.		Equal to	5152.0	Fine ozs.

Make all calculations on
this sheet.

On this charge the flux used was,

40.0# soda ash, 35.0# borax and 65.0# silica.

Amalgamation Plant Foreman

Refining furnace.

This is an oil fired, reverberatory furnace with a 3'-2"x5'-2" hearth lined with magnesite brick and holds a charge of 2000# to 2200# of base metal and sponge or 23,000 Oz. to 25,000 Oz. of refined silver bullion. In blowing in the furnace, the fire is started and the temperature gradually raised for four or five hours after which the charge is put in. After the charge is melted and before the slag has become plastic, skimming begins and the rough slag, composed largely of silica in the sponge, is raked off through the charging door. This first slag is sent to the ball mill with the slag from the tilting furnace, where it is ground and the values concentrated on a Wilfley table. As soon as the surface of the silver is well exposed an air blast is turned on and the scum formed is raked off at intervals of 15 minutes to $\frac{1}{2}$ hour till a slag no longer forms. This second skimming, or slag, is returned to the tilting furnace for remelting. When a permanently clear surface of silver is exposed the furnace is ready to tap.

About twenty minutes before tapping, the surface of the silver is well covered with charcoal and the charge rabbled. This serves to remove the oxygen from the refined

Page 21.

silver so that the bars do not sprout when poured. Immediately before tapping, a sample is dipped from the furnace for assay. It is found that the bars do not differ in fineness and that the one sample will serve for the entire heat. The silver is drawn off through a tap hole in the side of the furnace which is opened with a one inch bar. After the hole is opened the silver runs thru a cast iron spout into moulds, previously heated, set on a steel car. The moulds are placed side by side and as each is filled the car is moved along till the next mould comes under the spout. Each mould is fitted with a lip, or projection, which extends over the side of the next mould to prevent the spilling of the molten silver. After the bars have cooled they are trimmed and ~~weigh~~ weighed and the serial number of the bar, and the weight and the fineness are stamped on each bar. They are then shipped to the Buffalo Mines, Limited, London, Eng. and sold on the London market when the prices are most favorable.

It is always the aim to make a bullion 996.0 fine or better, thus avoiding a refining charge on the silver sold. The time to complete a heat varies from fourteen to twenty hours. The cost per Oz. for refining is as follows:-

Page 22.

Labor -----	0.030¢
Oil -----	0.098¢
Air -----	0.001¢
Repairs -----	<u>0.030¢</u>
Total per Oz.	0.159¢

A sample charge sheet for the refining furnace will be found on page 23.

Additional discussion.

1. Tube mill.
2. Precipitation of cyanide solutions.
3. Refining furnace.
4. Laboratory methods in use here.

While every step is of importance, the ones enumerated above probably have the greatest bearing on the successful operation of the plant and are deserving of additional comment.

The tube mill of amalgamation barrel.

The running of this machine has a greater bearing on the success of the process than any other factor. It is the most difficult machine upon which to make accurate observations in the course of its running and there are a greater number of factors influencing the action in the tube mill than in any of the other machines. Many of these

Amalgamation Plant—Refining Furnace Report

Heat No. 21.

Date April 29, 1914.

1725#	Retorted Silver	23697.0	Troy ozs.	-----	Fine equal to	19617.0	Fine ozs.
372#	Charged Bullion	6489.0	" "	-----	" "	5845.0	" "
45#	Scrap	656.0	" "	990.0	" "	649.0	" "
Total Charge		30842.0	Troy ozs.		Equal to	26111.0	Fine ozs.

Produced	23 Bars Bullion	24435.95	Troy ozs.	997.5	Fine equal to	24374.86	Fine ozs.
	70# Scrap	1020.8	" "		" "	1010.6	" "
		275#	Av. to Ball mill.				
	Slag	72.0	Lbs. Avoir. (To Tilting Furnace)				
Total		25456.75	Troy ozs.		Equal to	25385.46	Fine ozs.

Time charged	3:00 P. M.	a.m.	Assay at start of heat	Fine
		p.m.		
Time tapped	9:00 A. M.	a.m.	" middle "	"
		p.m.		
Time of heat	18.0	hours	minutes	" end " 997.5 "

(Attach pyrometer record sheet to this report)

Make all calculations on this sheet

Amalgamation Plant Foreman

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factors are small and yet they exert a very great influence on the results obtained.

As noted before the amalgamation barrel is charged intermittently. The charge is constantly aerated by means of compressed air which is admitted thru the bearing at one end of the mill and discharged at the other end thru a steel upright, or arm, extending above the arm when the mill is loaded and to within two inches of the lining of the mill. The upright is connected with a pipe extending thru the end bearing where the air is discharged. The air pipe at each end of the mill is fitted with a stuffing box to prevent leaks.

The aim in the tube mill is, of course, to recover as much amalgam the greatest amount of silver possible with the least expense. Since the mercury is the largest item which enters the problem it will be given the greatest prominence in the following discussion. The mercury loss may be divided into three separate classes, floured mercury, mercury going into the residues as the sulphide, and the mercury which goes into solution. While this last is eventually recovered, the expense of precipitation and retorting

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together with the cyanide used up to put it in solution make it a loss from the standpoint of the cost of recovery. The floured mercury is well recovered by the mechanical appliances so the big consideration is the mercury lost as the sulphide. The object then is to always make this as small as possible. It may be added here that the KCN is added to the solution in the tube mill, rather to keep the mercury active than to act as a solvent for the silver. Following are data and observations collected at different times in the course of the running of the plant.

The following data was collected on tube mill charge No. 96.

Tabulation of results on page 26.

Curves plotted on page No. 27.

Charge sheet for Chg. No. 96 on page No. 28.

Page 26.

Data on tube mill charge No. 96.

Time of sample.	KCN #/Ton.	P. A. in terms of CaO #/Ton.	Ag, Oz./T.
11:30 P. M.	89.4	11.5	52.4
12:30 A. M.	88.0	14.2	62.4
1:30 Do.	85.8	14.4	73.2
2:30 "	83.4	14.4	83.8
3:30 "	80.4	14.4	111.0
4:30 "	76.0	15.4	126.0
5:30 "	74.0	15.4	144.0
6:30 "	71.6	16.0	153.0
7:30 "	66.2	16.4	156.0
8:30 "	64.6	16.4	167.0
Sol. discharged	58.7	16.2	159.0

Pulp heads assayed 2893.0 Oz./T.

Pulp tails assayed 89.0 Oz./T.

From the above it will be seen that,

2.71% of the total silver was cyanided.

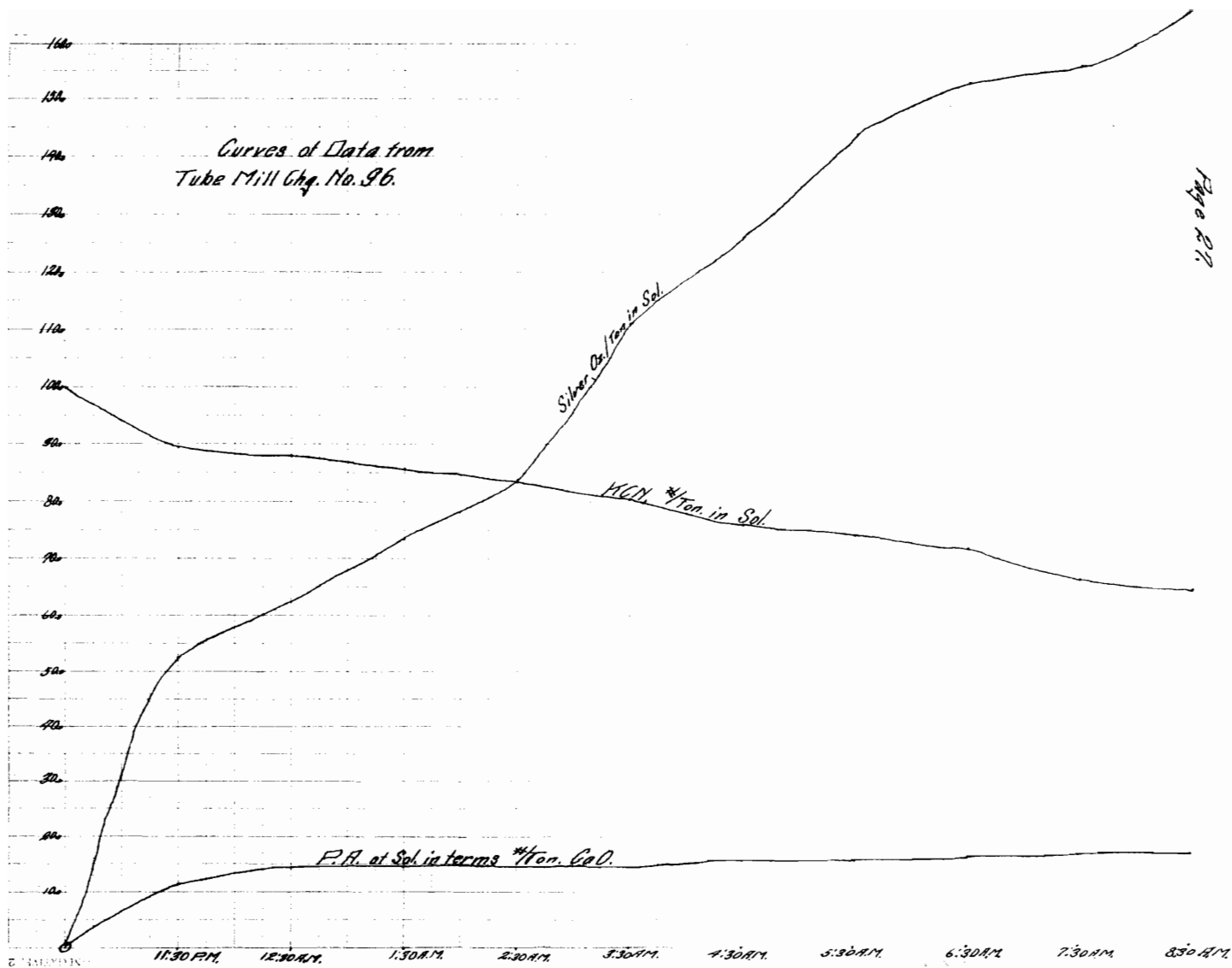
94.01% of the " " " amalgamated.

96.72% " " " " extracted in the tube mill.

A screen analysis of the pulp discharged from tube mill charge No. 96 was made to determine where the mercury and silver values are contained. The results of this will be found on page No.29.

Curves of Data from
Tube Mill Chg. No. 96.

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Amalgamation Barrel Record

Charge No. 96.

Date June 29, 1913.

G. A. T. - 55608

CHARGING HOPPER		WEIGHTS		MERCURY AND PEBBLES		
	No.	Gross	Tare			
Charge of Jig Ore.	1	2670.0	480.0	Lbs. Charged of Mercury	8000.0	
	2	2540.0	Do.	Ratio of Mercury to Ore	0.99	
	3	2700.0	"	Lbs. Pebbles Charged	None.	
	4	2110.0	"	SOLUTION		
	5			Tons Charged	2.0	
	6			Strength in Cyanide	Lbs. per Ton	Total Lbs.
	7			Charged in Solution	20.0	40.0
	8			Lbs. Cyanide added	80.0	160.0
	9			Made up to	100.0	200.0
Gross Weights	10020.0		Discharged	58.7	117.4	
Tare Weights	1920.0		Loss	41.3	82.6	
Moisture %			PROTECTIVE ALKALINITY			
Moisture Tare			Charged in Solution			
Total Tare			Lbs. Lime Added (CaO)	None.		
Net Weight of Ore in Lbs.		8100.0	Made up to	16.2		
Net Weight of Ore in Tons		4.05	Discharged			
Assay Value per Ton		2892.0	Loss			
Total Ounces of Silver		11717.0				

Remarks :

Make all calculations on back of this sheet

Amalgamation Plant Foreman

Screen analysis of pulp from tube mill charge No. 96.

Description of sample.	% of whole.	Oz./T.,	Ag.	% Hg.	% of total value in	
					Ag.	Hg.
On 50 mesh.	0.37	474.0	----	----	1.84	-----
" 100 "	1.08	730.0	2.90	----	8.25	5.51
" 150 "	2.02	280.0	0.64	----	5.94	2.31
" 200 "	2.66	193.0	0.36	----	5.38	1.72
Sand thru 200 mesh, dry.	19.25	145.0	0.20	----	29.30	6.89
" " 200 " , wet.	9.95	112.0	0.26	----	11.30	5.19
Slime thru 200 "	64.70	55.0	0.68	----	37.40	78.80

From the above it follows that;

93.90% of the material passes 200 mesh.

78.00% of the silver value passes 200 mesh.

90.88% of the mercury contained passes 200 mesh.

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From these calculations it will be seen that the material on 200 mesh is slightly higher in both mercury and silver than that thru 200 mesh. This is more pronounced in the case of the silver and indicates that in order to free the values so they will yield to the tube mill treatment it is necessary to have all the ore very finely ground. Since the slime thru 200 mesh gave the smallest assay for silver one might conclude that the whole bulk of the ore should be reduced to a slime. This is not, however, the case since other economic considerations enter here. In the first place the cost of grinding this last small amount of material is disproportionately high. It is also true that a small amount of sand is very beneficial in aiding filtration. It is fortunately found to be the case that even these coarser sands are sufficiently reduced to yield their values to the subsequent cyanide treatment in the agitation tanks.

A similar screen test was made on the pulp discharged from tube mill charge No. 81.

A tabulation of the results will be found on page No. 31.

The tube mill charge sheet for the corresponding charge will be found on page No. 32.

Screen analysis on pulp from tube mill charge No. 81.

Description of sample.	% material	-----Assays-----			--% of total in--		
		Ag, Oz./T.	% Hg.	% S.	Ag.	Hg.	S.
On 50 mesh.	0.23	1252.0	----	----	2.74	---	----
" 100 "	2.70	343.0	0.34	2.60	8.83	0.79	1.15
" 150 "	4.85	155.0	0.30	3.49	7.17	1.28	2.79
" 200 "	7.85	116.0	0.36	4.72	8.68	2.46	6.01
Thru 200 mesh, sand, dry	18.70	174.0	0.52	9.38	30.95	8.50	28.85
" 200 " " wet	25.60	82.5	0.60	5.54	20.10	13.56	23.43
" 200 " slime	40.00	56.2	2.10	5.75	21.40	73.40	37.70

Pulp heads assayed 1432.0 Oz./T. Ag.

" tails " 105.0 " " ".

From the above it follows that;

90.50% of the silver was amalgamated,

2.02% " " " " cyanided,

84.5% of the material passes 200 mesh,

72.5% of the silver remaining passes 200 mesh,

THE BUFFALO MINES, LIMITED

Amalgamation Barrel Record

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Charge No. 81.

Date June 12, 1913.

G.A.T.-55608

CHARGING HOPPER		WEIGHTS		MERCURY AND PEBBLES		
	No.	Gross	Tare			
Charge of Table Concentrate.	1	2120.0	480.0	Lbs. Charged of Mercury	8000.0	
	2	2050.0	DO.	Ratio of Mercury to Ore	1.0	
	3	1925.0	"	Lbs. Pebbles Charged	200.0	
	4	2185.0	"	SOLUTION		
	5	2135.0	"	Tons Charged	2.0	
	6			Strength in Cyanide	Lbs. per Ton	Total Lbs.
	7			Charged in Solution	30.0	60.0
	8			Lbs. Cyanide added	70.0	140.0
	9			Made up to	100.0	200.0
Gross Weights	10415.0			Discharged	41.5	83.0
Tare Weights	2400.0			Loss	58.5	117.0
Moisture %				PROTECTIVE ALKALINITY		
Moisture Tare				Charged in Solution	7.0	14.0
Total Tare				Lbs. Lime Added (CaO)	8.0	16.0
Net Weight of Ore in Lbs.		8015.0		Made up to	15.0	30.0
Net Weight of Ore in Tons		4.007		Discharged	15.1	30.2
Assay Value per Ton		1432.0		Loss	0.1	0.2
Total Ounces of Silver		5738.0				

Remarks :

Make all calculations on back of this sheet

Amalgamation Plant Foreman

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95.46% of the mercury contained passes 200 mesh,
90.0% " " sulphur " " 200 " .

It will be noted that the results on charge No. 81, composed of table concentrate, are not as good as those obtained on charge No. 96, which was jig concentrate. It is true that the treatment of the table concentrate is more difficult than that of the jigs and equally good results cannot be obtained in the tube mill. This is due to the fact that a greater amount of the complex sulphides and arsenides exist in the table concentrate than in the product from the jigs. In the case of the table concentrate it is necessary to depend more on the subsequent cyanide treatment for the complete extraction of the silver.

It was early concluded that, aside from the varying character of the ore, the air admitted to the mill was the greatest single factor in governing the mercury loss. Both the pressure maintained and the volume of air used are factors the probably the latter is the greater. A number of tests with various air pressures and volumes were made giving special attention to the charges of table concentrate.

A test using various air pressures was made on tube mill charge No. 114. The charge sheet will be found on page 34, the tabulated observations on page 35, and the plotted curves on page 36.

THE BUFFALO MINES, LIMITED

Amalgamation Barrel Record

Page 34,

Charge No. 114.

Date July 25, 1913.

G.A.T. 53485

CHARGING HOPPER				MERCURY AND PEBBLES		
	No.	WEIGHTS				
		Gross	Tare			
Table concentrate	1	2140.0	480.0	Lbs. Charged of Mercury	8500.0	
	2	2180.0	480.0	Ratio of Mercury to Ore	0.84	
	3	2125.0	480.0	Lbs. Pebbles Charged	250.0	
	4	2200.0	480.0	SOLUTION		
	5	2110.0	480.0			
	6	2215.0	480.0	Tons Charged	2 1/2 tons water.	
	7			Strength in Cyanide	Lbs. per Ton	Total Lbs.
	8			Charged in Solution	Nil.	Nil.
	9			Lbs. Cyanide added	100.0	250.0
Gross Weights		12970.0		Made up to	100.0	250.0
Tare Weights		2880.0		Discharged	37.2	92.0
Moisture %				Loss	62.8	157.0
Moisture Tare				PROTECTIVE ALKALINITY		
Total Tare						
Net Weight of Ore in Lbs.		10090.0		Charged in Solution	Nil.	Nil.
Net Weight of Ore in Tons		5.045		Lbs. Lime Added (CaO)	Nil.	Nil.
Assay Value per Ton		1200.4		Made up to	Nil.	Nil.
Total Ounces of Silver		6056.0		Discharged	12.6	34.0
				Net Gain	12.6	34.0

Remarks :

Mill run 10.0 Hrs.

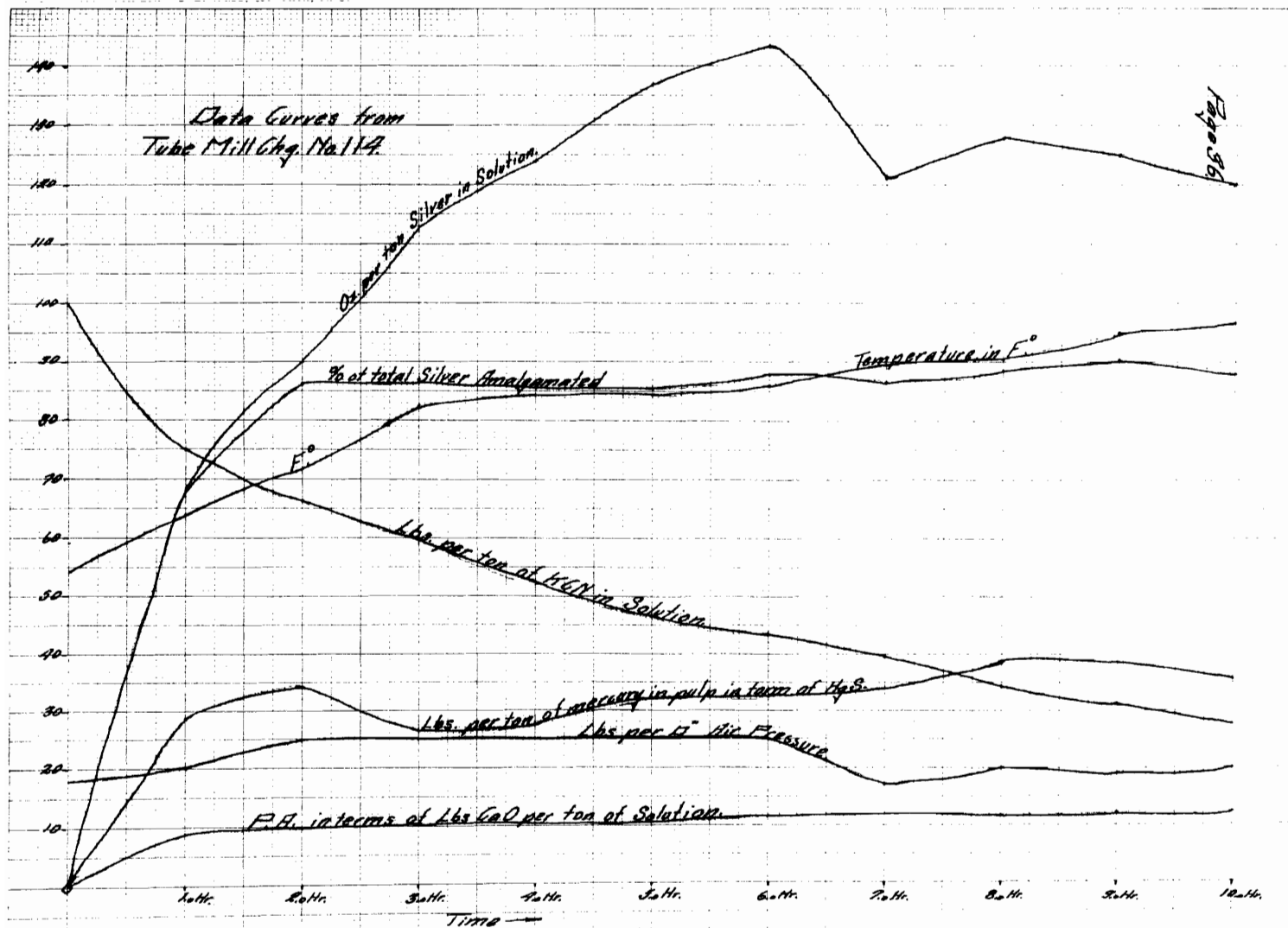
Make all calculations on back of this sheet

Amalgamation Plant Foreman

Data for curves on tube mill charge No. 114.

Hourly sample No.	% of Ag amalgamated.	Ag in Sol.	#/T. Hg as HgS in pulp.	KOH, #/T.	P. A. in terms of #/T. CaO.	#/Sq. in.	Temperature in degrees F.
1.	81.5	68.0	28.8	75.0	8.9	20.0	?
2.	86.2	90.0	34.2	66.1	9.6	25.0	71.6
3.	86.5	113.0	26.2	59.8	10.1	25.0	82.5
4.	85.5	124.0	27.6	52.6	10.3	25.0	84.3
5.	85.2	137.0	32.2	46.2	10.6	25.0	84.3
6.	88.0	143.4	32.6	43.6	11.6	25.0	86.0
7.	86.5	121.0	34.0	39.7	12.0	17.0	89.7
8.	88.7	128.4	38.8	34.4	12.0	20.0	90.5
9.	90.2	125.0	38.4	31.3	12.2	19.0	95.0
10.	88.0	120.4	35.4	27.5	12.2	20.0	96.9

It is to be remembered that these samples were drawn thru the axis of the mill while it was in motion. The pulp samples may not be true but are the best obtainable.



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From the steepness of these curves and their flattening out at the end of a few hours one can see that all chemical action is very prompt and soon ceases. The additional running is resorted to to accomplish a further reduction in size of the ore particles, which aids in the cyanide treatment following the tube mill treatment.

A series of tests was also made using different volumes of air with no pressure on the tube mill. Following is one of these tests on charge No. 24 consisting of table concentrate.

Tube mill charge sheet for charge No. 24 will be found on page 38, tabulation of results on page 39 and the curves plotted on page 40.

Other tests were made using more air, less air and no air at all. The other tests will not be given here in detail but the results obtained will be kept in mind in the discussion following.

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Amalgamation Barrel Record

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Charge No. 24.

Date Feb. 17, 1914.

G. A. T. - 55608

CHARGING HOPPER			MERCURY AND PEBBLES		
	No.	WEIGHTS			
		Gross	Tare		
Table concentrate	1	2180.0	480.0	Lbs. Charged of Mercury	11000.0
	2	2180.0	480.0	Ratio of Mercury to Ore	1.00
	3	2175.0	480.0	Lbs. Pebbles Charged	400.0
	4	2110.0	480.0	SOLUTION	
	5	2120.0	480.0	Tons Charged	2 1/2 tons water.
	6	2075.0	480.0	Strength in Cyanide	Lbs. per Ton
	7	920.0	480.0	Charged in Solution	Total Lbs.
	8			Lbs. Cyanide added	Nil.
	9			Made up to	Nil.
Gross Weights		13760.0		Discharged	100.0
Tare Weights		2360.0		Loss	250.0
Moisture %					100.0
Moisture Tare					18.2
Total Tare					45.5
Net Weight of Ore in Lbs.		10400.0			204.5
Net Weight of Ore in Tons		5.2		PROTECTIVE ALKALINITY	
Assay Value per Ton		850.0		Charged in Solution	Nil.
Total Ounces of Silver		4420.0		Lbs. Lime Added (CaO)	Nil.
				Made up to	Nil.
				Discharged	13.6
				Loss	34.0
				Gain	13.6

Remarks:

Grind 10.0 Hrs.

Make all calculations on back of this sheet

Amalgamation Plant Foreman

BUFFALO MINES, LIMITED.

EXPERIMENT TO DETERMINE THE EFFECT OF DIFFERENT VOLUMES OF AIR ON THE *Page 33* MERCURY LOSS IN THE TUBE MILL.

TEST NO. 1 KIND OF ORE Tables CHARGE NO. 24 DATE Feb. 12 1914.
 Weight of ore charged 10,400.0 lbs. Weight of Hg charged 14,000.0 lbs.
 " " Sol. " 5,000.0 " . Strength Sol. Chged. 100.0 #/T?KCN.

HOURLY SAMPLES.

No.	Time taken.	Temp. $^{\circ}$ F.	Cu Ft Air Min.	Mercury assay on			Titration of solution.		Silver assay solution.
				Residue as		Solution.	KCN %/Ton	CaO %/Ton	
				Sulphd.	Metallic.				
1	12:30 PM	11.0	67.0	0.06%	0.24%	Nil %	44.0	3.9	83.0
2	1:30 "	13.0	16.0	0.45%	0.09%	Trace	56.3	6.8	151.8
3	2:30 "	17.0	"	0.87%	0.13%	0.075%	47.5	7.6	207.2
4	3:30 "	19.0	"	1.56%	0.04%	0.188%	41.0	8.8	223.3
5	4:30 "	21.0	"	1.52%	0.34%	0.344%	35.5	10.1	228.0
6	5:30 "	20.0	"	1.90%	0.12%	0.436%	28.0	10.2	205.6
7	6:30 "	23.5	"	1.75%	—	0.640%	26.1	11.5	216.0
8	7:30 "	25.0	"	1.81%	0.19%	0.803%	24.8	12.2	204.8
9	8:30 "	22.0	"	1.84%	0.36%	1.045%	20.9	13.3	189.8
10	9:30 "	27.0	"	2.89%	0.57%	1.088%	19.8	13.4	180.8

Time charged 11:30 AM

Time discharged 9:30 PM

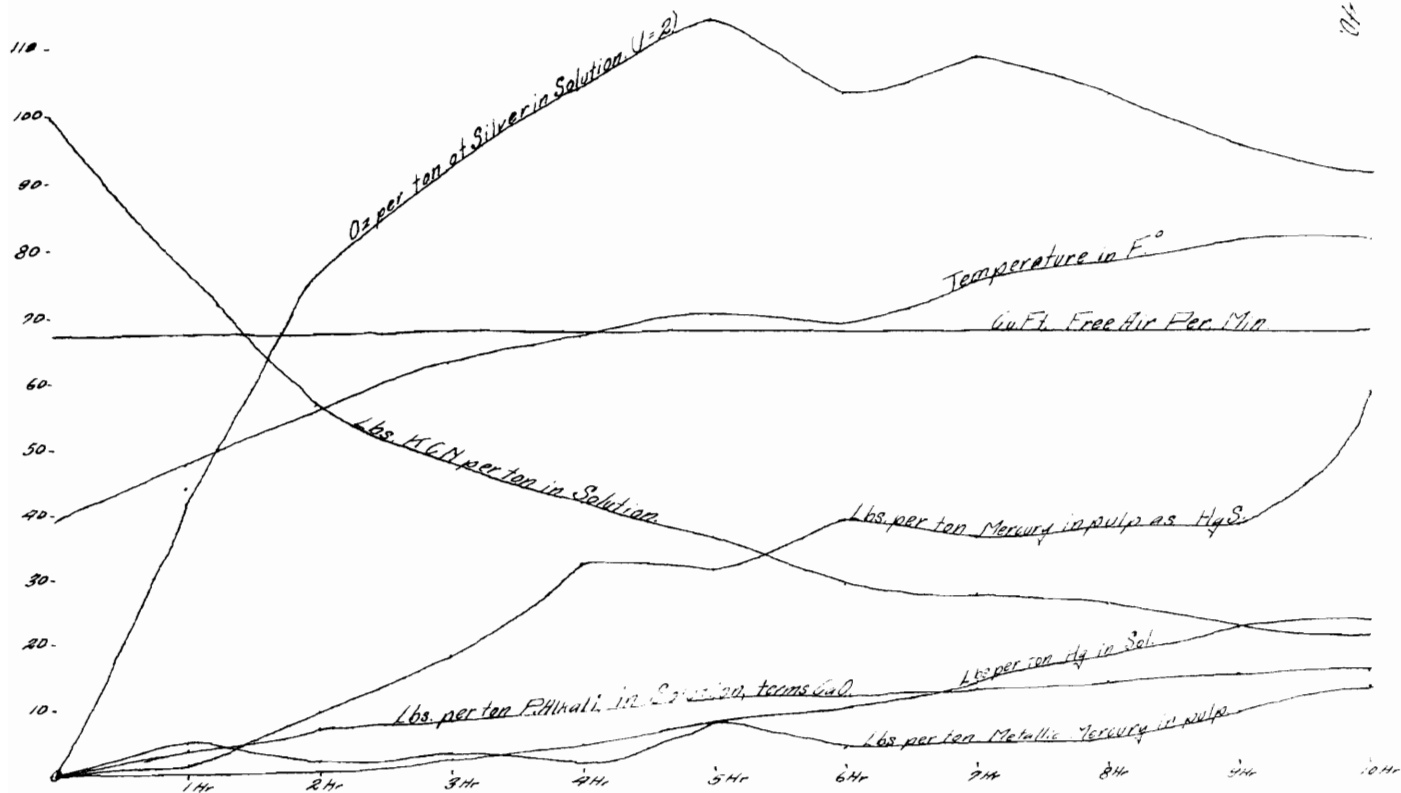
Head assay in silver 850.0 Oz/T.

Residue assay in silver 129.5 Oz/T., as discharged from tube mill.

Head assay in sulphur — %

Remarks;— In the above the "CaO %/T" is really the alkalinity expressed in terms of CaO.

Curves of Data from
Tube Mill Charge No. 24.



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The tests made indicate that too much care cannot be used in admitting the air to the tube mill while running. Some air is essential while at the same time too much air is equally bad. If too little air is used the loss of mercury in the pulp as mercury sulphide is excessive. If too much air is used a large amount of mercury enters the solution, which mercury is a financial loss as pointed out before. To be specific, just enough air should be admitted to keep the soluble sulphides, resulting from the ore, oxidized to sulphates or to KCNS. The charge should be sufficiently saturated with oxygen to accomplish this at the instant of the formation of the soluble sulphides. Any caustic sulphide which enters the solution at once effects a precipitation of either mercury or silver. If HgS is formed it passes with the pulp to the residues bin and is lost. If AgS is precipitated the metallic mercury present at once decomposes it forming HgS , the silver set free amalgamating with the excess mercury present. It will be seen then that any sulphide which enters the solution without being instantly oxidized results in a loss of mercury amounting to its chemical equivalent. To keep this loss of mercury down it is essential to have enough oxygen present to effect this

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oxidation. On the other hand, if too much air is present an excessive amount of metallic mercury is taken into solution by the cyanide. This also represents a loss.

Precipitation of silver from solutions.

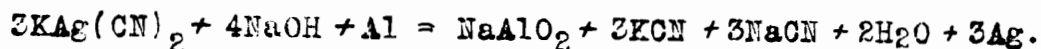
Three methods of precipitation of silver from cyanide solutions have been tried here. Any of the three would accomplish the end but aluminum dust was found to be most satisfactory and is used exclusively at the present time.

It was found that zinc shavings would precipitate the silver from the solution as long as a bright surface of the zinc could be kept exposed. Owing to the copper and mercury in the solutions the zinc shavings required frequent cleaning due to the fact that they soon became coated with copper and mercury, stopping the action of the cyanide on the zinc and retaining the silver in the solution. Zinc dust was found to be an effective and complete precipitant of the silver as well as the mercury in solution if it was added slowly to the precipitation tank. However it was found that aluminum dust would effect a complete precipitation and at the same time offered a number of advantages over the zinc dust method. Some of these advantages are as follows;-

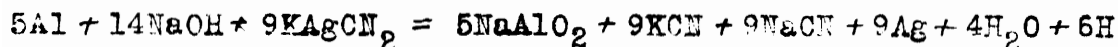
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1. It is cheaper.
2. It effects a regeneration of cyanide.
3. It keeps the mill solutions in a more active state.
4. A cleaner precipitate results which is more easily smelted.

The final theoretical equation for the precipitation of silver from cyanide solutions by this method may be written as follows;



In theory then, one atom of Al precipitates three atoms of silver or 27 of aluminum precipitates 324 of silver or the ratio of precipitation is 1:12 by weight. In this plant the records show that from 100 to 110 Oz. troy of silver are precipitated with one Lb. Av. of aluminum. It follows then that 60.0% of the theoretical efficiency of the aluminum is obtained. The equation of precipitation as it works out in practice at this plant is;



Where mercury is present with the silver in the KCN solution it is precipitated according to a similar equation using the double cyanide of mercury and giving metallic mercury as the precipitate.

It is to be born in mind that the relative concentration of the solution in both the metal and the

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caustic has a bearing on the way the reaction goes. Also the manner in which the aluminum dust is added exerts an influence on the results obtainable. To get the best results it is essential that the required amount of aluminum dust not be added too rapidly, that the agitation be sufficient to sink the dust promptly and that the caustic present be sufficient to completely consume the aluminum and yet not be strong enough to make the action too violent. The above results were obtained on mill solutions carrying from 100 to 150 Oz./T. silver and to which about four times as much caustic soda as aluminum was added by weight. A less concentrated solution of silver with very little caustic present will give a less efficiency for the aluminum.

Refining furnace.

A description of the running of the refining furnace has been given so the mechanical part will not be discussed further here.

It is found that care must be taken in order that all the silver shipped will be of commercial grade. It is no trouble to produce a bullion which is as fine as 999.5 plus if all the silver charged to the furnace be the sponge resulting from retorting of the amalgam.

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However, if a charge made up entirely of base bullion be run, the copper content of the base metal brings the fineness of the metal down. If the fineness falls below 996.0 a refining charge of $\frac{3}{4}$ per Oz. must be paid. This charge is avoided by carefully proportioning the amounts of base bullion and sponge which is put into the furnace each heat. As to the source of the copper it may be said that not all of it comes from the ore but some is introduced with the aluminum which is used as a precipitant of the silver from cyanide solutions. Care must therefore be used in order to secure aluminum dust which is free from copper.

Following are the charges as calculated for two heats to the refining furnace. The base bullion was obtained from low grade precipitates, high grade precipitates, concentrates from slags, and refining furnace skimmings and contained from 0.20% to 4.20% copper. The sponge was barren of copper.

Charge No. 10 to refining furnace:-

Ht. No.	12	tilt,	225#	base B.	0.700%	Cu	----	1.575#Cu.
"	"	13	"	90#	"	"	3.100%	"
"	"	18	"	158#	"	"	0.200%	"
"	"	19	"	165#	"	"	0.200%	"

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Ht. No. 20 tilt,	208# base B. @ 0.200% Cu	----	0.416# Cu
Scrap from refining furnace, containing		-----	0.002# "
Sponge from retorts, <u>1332#</u> ,	"	-----	<u>0.000# "</u>
Total charge,	2224# metal. Total copper,		5.429# Cu

.

Charge No. 11 to refining furnace;-

Ht. No. 17 tilt,	175# base B. @ 0.900% copper	--	1.575# Cu
" " 21 " ,	47# " " " 0.300%	-	0.141# "
" " 22 " ,	297# " " " 0.200%	-	0.594# "
" " 23 " ,	70# " " " 4.200%	-	2.940# "
Sponge, retorts, <u>1530#</u>	containing no copper	-	<u>0.000# "</u>
Total charge,	2119# metal containing	-----	5.250# Cu

. . . ;

Charge No. 10 produced 23,327.0 fine ounces of silver. 5.429# Av. or 79.0 troy Oz. of copper went into the charge.

A reverberatory furnace such as is used here for refining is capable of removing every impurity encountered in the silver except copper. Small amounts of this is removed with the slag.

Assuming that all the copper charged to the furnace remains in the refined bullion and that the only impurity in the refined silver is copper, the calculated assay of the refined product, in case of charge

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No. 10, is 996.6 fine. The actual assay of the refined bullion was 997.2 fine. The copper slagged off then was 14.7% of the amount charged to the furnace.

Making like assumptions in the case of charge No. 11, the calculated assay is 996.6 fine. The final product assayed 997.3 fine. The copper slagged off in this case then was 16.2% of that charged to the furnace.

It is to be remembered that of the copper which is slagged off of the charge in the refining furnace the larger part goes to the second skimmings which are remelted in the tilting furnace. Here the copper tends to collect in the base bullion so that the most of it again finds its way back to the refining furnace. The result is then that the only way the copper can be finally disposed of is in the refined bullion. This is accomplished without disadvantage to the mine by carefully mixing the charges going to the refining furnace.

Laboratory methods in use here.

No attempt will be made to give minute descriptions of the various methods used here as most of them are to be found in the various technical books dealing with chemistry. There are a few ~~novelties~~ novelties in the practice here tho that are deserving of mention. Two of these will be discussed:

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I. Quick method for determination of mercury.

II. Method for determining the fineness of the silver bullion sold.

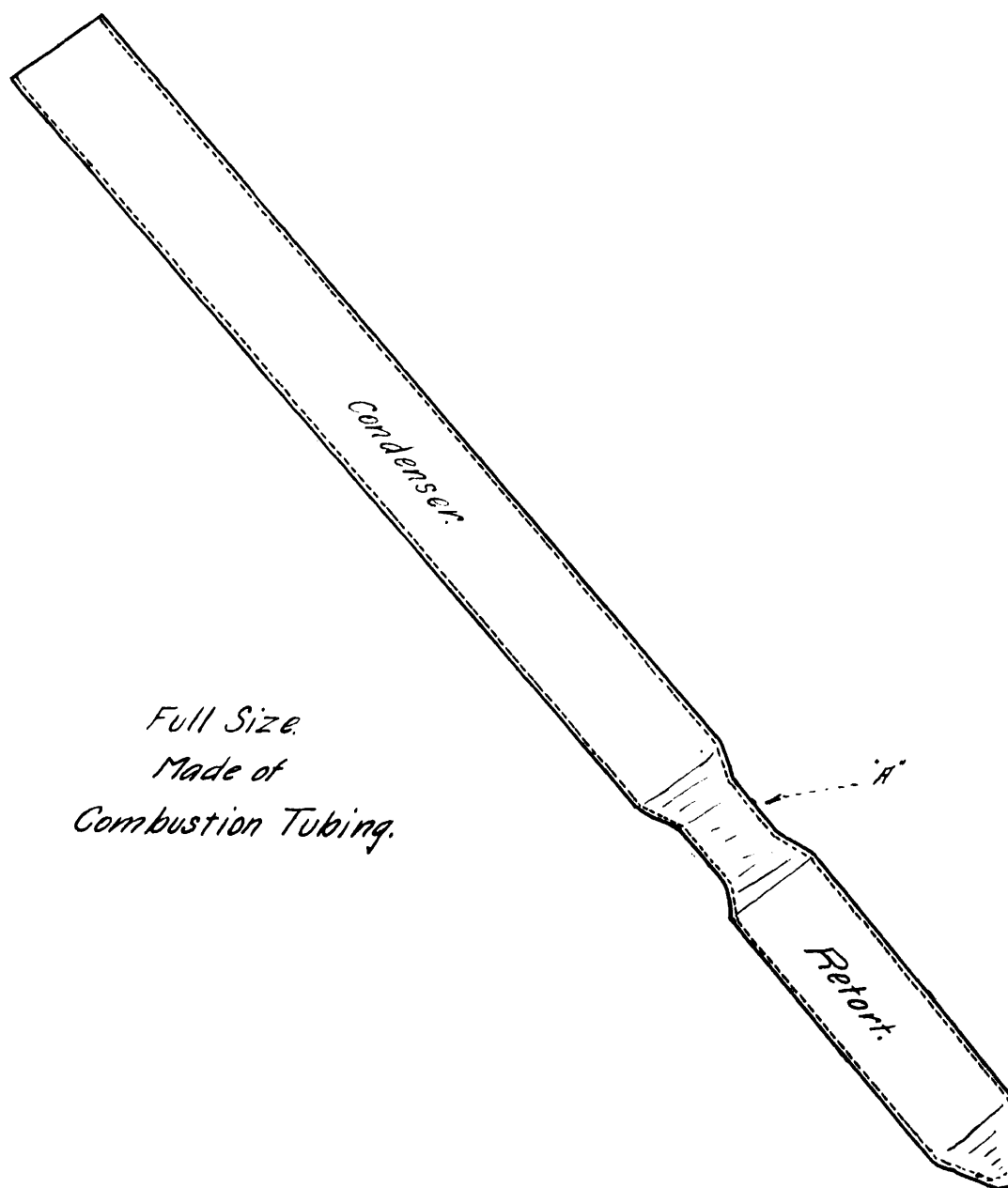
Mercury Determination.

The wet methods for the determination of mercury involve a number of delicate operations which consume much time. They are inconvenient and unsatisfactory in many cases for numerous reasons. Where a large number of daily determinations are to be made on various products the method here described is much more satisfactory than the others now at hand.

The method in use at this plant takes advantage of the fact that mercury is volatile and that it readily amalgamates with gold. The method is worked as follows;-

A portion of the sample is weighed out and mixed with iron filings and placed in a hard glass tube sealed at one end and heated and partially drawn out a short distance from the end making a bulb which serves as the retorting chamber. (See Fig. page 49.) The straight portion of the tube acts as the condenser for the mercury. Cover the charge with a small quantity of iron filings. The tube is then heated over a gasoline torch, the charge being brought to a red heat and the upper part of the tube kept cool. The iron filings serve

Drawing of Tube Used in Mercury Determination.



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to decompose any mercury compounds present. The mercury distills off and condenses in the upper portion of the tube. After action ceases the tube is sealed off at the point "A" and the portion of the tube containing the charge discarded. The mercury is collected by placing in the tube several gold beads weighing about 100 mgm. each together with a 0.1% potassium cyanide solution and shaking vigorously for several minutes. The beads are then washed with water and alcohol and weighed. After driving the mercury from the beads with heat they are again weighed, the difference representing the mercury contained in the sample.

Where a dozen mercury determinations are to be made the time consumed for each determination is about ten minutes. This method serves well for pulp or sponge. It is advantageous to take a portion of the sample which will contain about 50.0 mgm. ^{or less} of mercury.

To make an assay of the mercury contained in a cyanide solution take 10.0 c.c. of the solution, place in a large test tube and add a few drops of concentrated sodium hydrate solution and a small portion of aluminum dust. This effects a complete precipitation of the mercury present. Now filter thru an asbestos medium on a Gooch vacuum filter. Dry the

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precipitate at a low temperature and remove the asbestos and the precipitate and charge to a combustion-tube-retort and proceed as with a pulp sample.

This method for mercury is very satisfactory for this class of work and is correct to within 1.0% of the mercury contained. On a sample which carries 1.0% of mercury this makes the method correct to 0.01% of the weight of the sample which is quite close enough.

II. Method for the determination of the fineness of the silver bullion shipped.

There are many methods available for this determination, a number of which have been used here at different times. The one which has been most satisfactory and the one which is now used is an indirect method by which the impurity of the sample is determined. The method is based upon the assumption that the only impurity in the refined silver is copper. The copper assay value is deducted from 1000.0 to obtain the fineness of the sample in silver. The method would not be applicable except where the foregoing assumption is true but where the method can be used it offers the added advantage that a much larger portion of the sample may be used for assay than where one of the direct methods are used.

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Other things being equal, this greatly reduces the chance of error. By using a 10.0 gm. portion for assay the fineness may be determined to one tenth point in fineness with precision. The method has been checked against the potassium sulpho cyanide method and against the fire assay and has been found to give ^{more} accurate results with greater ease.

Method;- Dissolve a 10.0 gm. portion of the sample in the least amount of nitric acid possible. Evaporate to dryness and discoloration of the residue. After thus removing the last of the nitric acid add 300 c.c. boiling water. Precipitate the silver with an excess of hydrochloric acid. (5 c.c. added rapidly.) Stir violently to break up the precipitate. Heat to boiling but avoid bumping. Filter and wash well with hot water. Heat filtrate to boiling and pass in excess hydrogen sulphide. Filter and wash well. Dissolve the precipitate on the paper in a dilute solution of hot nitric acid. Bring the solution to boiling heat. Cool and add excess of ammonia. Boil off excess ammonia. Add 5 c.c. concentrated acetic acid and bring to boiling heat. Dilute to 100 c.c. Add 3 gms. of potassium iodide and a little starch solution. Titrate for copper. Deduct the copper assay from the total to get the amount of silver contained.

Comparison of Smelting Costs.

Cost for treatment at smelter;

Freight - - - - -	\$10.00
Treatment charge - - - - -	15.00
5.0% of 1500 Oz. @ 60¢ - - - - -	45.00
Refining charge, 1¢ per Oz. - - - - -	<u>15.00</u>
Total cost - - - - -	<u>\$85.00</u>

Cost of treatment here;

The total cost of treatment here including interest and depreciation and every item of expense is \$70.00 per ton.

This shows a profit of \$15.00 per ton on treatment alone. In addition to this the residue is still the property of the mine and is available for sale, payment being received for 75.0% of the remaining silver. The company is recovering mercury from the residue at a profit of \$10.00 per ton which is a credit to be deducted from the cost of treatment as shown above.

The profit per ton that the plant yields then is;-

Saving on treatment - - - - -	\$15.00
Additional silver paid for,	
37.5 Oz. @ 60¢ - - - - -	22.50
Credit, mercury extracted - - - - -	<u>10.00</u>
Total profit - - - - -	<u>\$47.50</u>

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Other advantages which at present cannot be reduced to a cash value are,

1. Future sale of cobalt, nickel and arsenic contained in the residue.

2. Profit recieved by taking advantage of the silver market at the most opportune times.

The above considerations show that the plant has been a paying investment.

. Finis.